CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The world's surface temperature has increased since the inception of the industrial revolution (Jarvis *et al*., 1989; Wang and Polglase, 1995). Global warming statistics compiled by National Aeronautics and Space Administration's Goddard Institute for Space Studies (NASA-GISS) has revealed that the average global temperatures have soared by 0.8°C over the last century alone. Even more chilling is the fact that temperatures are increasing at an alarming rate of 0.15-0.2°C per decade (Butler, 2007). This rise in temperature (termed global warming) is caused by a progressive increase in some atmospheric gases, notably CO_2 and also includes methane, water vapour, ozone, chlorofluorocarbons and nitrous oxide (Cline, 2007). Unabated burning of fossil fuel, deforestation either through bush burning or elicit logging are activities that have increased the atmospheric CO_2 since the industrial revolution (Schimel, 1995; Jandl *et al.,* 2007). The present average atmospheric concentration of CO_2 is ca. 350 µmol of CO_2 per mole of dry air, and the concentration is rising at a rate of ca. 1.2 µmol mol-' per annum (Conway *et al.*, I988).The emissions of CO_2 have been dramatically increased within the last 50 years and are still increasing by almost 3% each year (Juery, 2007).

Contribution of CO_2 to greenhouse effect is mainly anthropogenic; about 77 percent of which comes from the combustion of fossil fuels and 22 percent of which is attributed to deforestation (IPCC, 2001; Jandl *et al.*, 2007). The vegetation and soils of the world's forests however contain about 125 percent of the carbon found in the atmosphere (Prentice *et al.,* 2001). When forests are burnt, degraded, or cleared, the opposite effect occurs: large amounts of carbon are released into the atmosphere as carbon dioxide along with other greenhouse gases. The burning of forests releases about two billion metric tons of carbon dioxide into the atmosphere each year, or about 22 percent of anthropogenic emissions of carbon dioxide. (Butler, 2007; Jandl *et al.*, 2007).

Through the process of photosynthesis, green plants are able to utilize CO_2 and give out O_2 which is beneficial for most animals. Natural forests, among their numerous benefits, are able to sequester CO_2 through photosynthesis. This helps to balance the proportion of atmospheric gases. However, unsustainable use of the forests through clearing has led to deforestation and forest degradation which demobilizes carbon stored in trees (Benhin, 2006; Jandl *et al.*, 2007). The world's forests as indicated by FAO (2009), experience annual deforestation of 14.6million ha per year as against annual increase of 5.2million ha.

Expansion of existing forest resource through aforestation and other silvicultural practices could help avert this problem of vegetation loss which invariably will serve as carbon sink (Kraenzel *et al.*, 2003; Jandl *et al.*, 2007). The total area of forest plantations in the world is 130 million hectares which sequesters 11.8Pg C (Winjum and Schroeder, 1997). Teak plantations alone covers 2.25 million hectares world-wide and they rank third in terms of extensiveness (Krishnapillay, 2000). Plantation development which started in Ghana around the 1920s when explorations and expansions of European influence took place is still pursued as a means of catching up with the overwhelming use of timber and other forest resources. Today, trees are cultivated for a number of reasons which includes provision of timber and environmental services like carbon sequestration (Jandl *et al.*, 2007; Foli and Agyeman, 1996). A number of programmes have been initiated by international bodies such as United

Nations Convention on Climate Change, (UNCCC), Food and Agriculture Organization (FAO) and United Nations Development Programme (UNDP). Some of such programmes include REDD and REDD+ (Reducing Emissions from Forest Deforestation and Degradation), Clean Development Mechanism (CDM) and Joint Implementation, which employs techniques like carbon credits and carbon trading to encourage people to plant trees. There are also local plantation strategies by the Ghana government to expand the timber resource base and invariably serve as carbon sinks. There are the HIPC (Highly Indebted Poor Countries) plantations programme and the on-going National Government Plantation Development Programme which targets at planting thirty thousand acres of trees annually (Stanturf *et al.*, 2011). Tree planting to sequester carbon in general is perceived to be a cheaper option of slowing the increase in CO_2 concentrations than reducing fossil fuel energy use (Trexler and Kosloff, 1998). Knowledge on the amount of carbon a land use sequesters will aid decision makers and tree growers to make prudent decisions.

Agricultural ecosystems also have the potential to sequester carbon dioxide from the atmosphere and help mitigate global climatic changes to an extent (West, 2008). At the Conference of Parties (COP 6.5) meeting in Bonn, Germany (July 2001), agricultural sinks were recognized as emission offsets because CO_2 captured by plants and sequestered in soils is a large part of the global carbon cycle (Kaiser, 2000). However, depending on the type of agricultural system being used, agric lands could be a carbon source rather than carbon sink.

There is a considerable concern that land use changes may lead to depletion in soil carbon which will consequently lead to an increase in atmospheric carbon. (Houghton, 1999; IPCC, 2007). This notwithstanding, a report from Royal society (2001) suggests that tropical forestation, agroforestry and regeneration together accounts for 39% of the potential for using land management as carbon sink which mitigates global emissions of CO_2.

Among the numerous challenges facing forest management and aforestation practice is the opportunity cost of using lands for tree planting instead of investing land in another venture. Land is scare and therefore its expected benefits usually determine its ultimate use. It is therefore imperative for tree growers to have a fore knowledge of the estimated amount of carbon that their stand of trees sequesters. This could serve as an incentive for tree planting since land is scare and growing trees by itself is not an attractive venture because of long duration taken for trees to mature.

1.2 Justification for the study

Carbon dioxide is a major greenhouse gas that contributes immensely to global warming. Trees, through carbon cycle and photosynthesis are able to utilize carbon dioxide in the atmosphere and thus reduce this menace. Forests therefore serve as carbon sink. Land use conversion from forest to agriculture and/or plantations or vice visa leads to change in amount of carbon sequestered by vegetations and soils.

Private individuals and organizations are being encouraged to go into plantations so as to help curb this problem of climate change. Foresters, agriculturists and tree growers alike should be informed about the change in carbon associated with transformation of one land use system to the other. Amount of carbon sequestered by each land use would also help our understanding of carbon budget of the four land use systems (Natural forest, Fallow land, Teak plantation and cropland).

Accurate estimation of forest biomass is crucial for a number of purposes including national development planning, as well as for scientific studies of ecosystem productivity, carbon and nutrient flows and for assessing the contribution of changes in forest lands to the global C cycle (Basuki *et al*., 2009). Particularly in the latter context, the estimation of the above-ground biomass with a sufficient accuracy to assess the variations in C stored in the forest is becoming increasingly important (Ketterings *et al*., 2001; Chave *et al*., 2005).

1.3 Main Objective

The main aim of the study was to assess the contribution of four land use systems in ameliorating global warming through reduction of atmospheric carbon and also to assess the change in amount of carbon lost or gained when one land use is converted to another.

1.4 Specific Objectives

The specific objectives of the present study were:

1. To quantify the CO_2 absorption capacity of natural forest, teak plantation, cultivated and fallow lands;

2. To determine CO_2 sequestration of five carbon pools of the terrestrial ecosystem;

3. To assess the emission and removal factors when one use system is converted to the other.

1.5 Research Questions

1. Which of the land use systems sequesters much carbon?
2. Do soils in natural forests contain the same carbon as soils of the other land use systems?
3. Which of the pools sequesters more carbon?
4. What is the emission factor when forest is converted to any of the land use systems?
5. What is the removal factor when other land use systems are converted to natural forest?

1.6 Hypothesis

1. Removal of forests (deforestation) to other land use types results in release of carbon dioxide to the atmosphere.
2. Soils of various land use systems contain varying amount of carbon.
3. Soils contain more carbon than vegetations.
4. Litter and shrubs under the various land use systems contain the same amount of carbon.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Climate Change and Global Warming

The world's climate has been warming ever since the inception of the industrial revolution. In recent times, climate change is seen as the major environmental problem facing the globe (Watson *et al.*, 2002). "Climate includes patterns of temperature, precipitation, humidity, wind and seasons over time. Climate change affects more than just a change in the weather; it refers to seasonal changes over a long period of time. These climate patterns play a fundamental role in shaping natural ecosystems, and the human economies and cultures that depend on them (http://www.ecy.wa.gov/climatechange/whatis.htm).

Because so many systems are tied to climate, a change in climate can affect many related aspects of where and how people, plants and animals live, such as food production, availability and use of water, and health risks (Watson *et al.*, 2002; Amisah *et al.*, 2009).

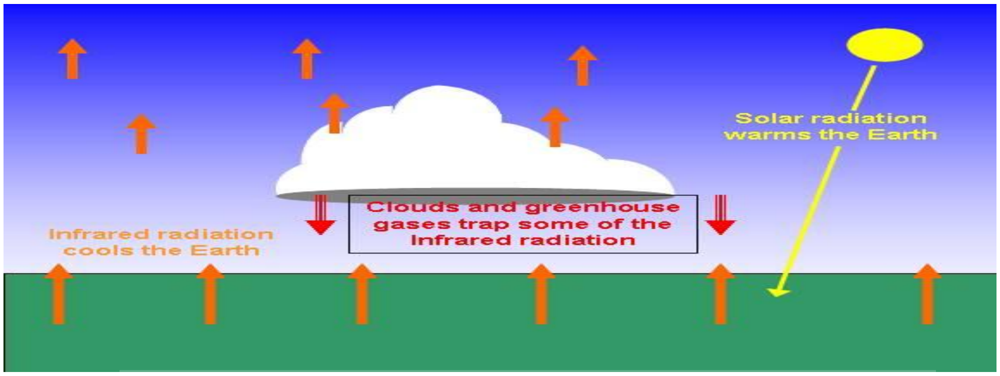
"Global warming causes climates to change."Global warming" refers to rising global temperatures, while "climate change" includes other more specific kinds of changes. Also, while "global warming" is planet-wide, "climate change" can refer to changes at the global, continental, regional and local levels. Even though a warming trend is global, different areas around the world will experience different specific changes in their climates, which will have unique impacts on their local plants, animals and people. A few areas might even get cooler rather than warmer (http://www.ecy.wa.gov/climatechange/whatis.htm).

Warmer global temperatures in the atmosphere and oceans leads to climate changes affecting rainfall patterns, storms and droughts, growing seasons, humidity, and sea level. It has been established that the world's mean surface temperature has increased by $0.6^{o}C$ (0.4-$0.8^{o}C$) over the last hundred years, with the year 1998 being the warmest year and the 1990's being the warmest decade (Watson *et al.*, 2002). According to IPCC (2007), global warming affects different areas and continents differently and even have different effects at nighttime and day time. The largest increase in temperature have occurred over the mid and high latitudes of northern continents, land areas have warmed more than oceans and nighttime is about half that of the increase in mean land surface air temperatures. Temperature increase over land has increase on the average to about $0.2^{o}C$ per decade, about twice the corresponding rate of increase in daytime maximum air temperatures. Some areas would experience beneficial effects from climate change whiles some area experiences detrimental effects. Places that would experience adverse effects are more than places that will experience beneficial effects (IPCC, 2007).

Global warming is seen as an anthropogenic (human- induced) phenomenon mainly because humans have, through their activities of raw material conversion, altered atmospheric constituents. Atmospheric gases like carbon dioxide, which is the main cause of global warming, and methane, is on the increase because of industrialization and its related activities like modernized agriculture and burning of fossil fuel (Butler, 2007). These gases in the atmosphere create a phenomenon called the "Green House Effect" which is discussed in the following sub-section.

2.2 Greenhouse gases and Green house effect

Green house effect as shown in Figure 1 , is a phenomenon where atmospheric gases such as carbon dioxide (CO_2), methane (CH_4), water vapour and nitrous oxides (N_2O) absorb long wavelength radiations emitted from the earth surface and thereby warming the globe (Pidwirny, 2006). When sunlight, which is short wavelength in the visible light portion of the electromagnetic spectrum, reaches the earth surface, the earth gets heated and emits long wavelength energy in the infrared portion. These long waves' posses less energy and therefore not all are able to get out of the atmosphere. The heat caused by the infrared radiation is absorbed by atmospheric gases which slows its escape from the atmosphere. Retention of the waves in the atmosphere causes the globe to warm which actually keeps life on earth. Without the greenhouse effect life on this planet would probably not exist as the average temperature of the Earth would be a chilly -18°, rather than the present 15°. However, increase in composition of these atmospheric gases mainly due to anthropogenic influence makes climate warm faster and more than what ecosystems can naturally adapt (Watson, 2002; Pidwirmy 2006 and West 2008). Water vapour, CO_2, CH_4, oxides of nitrogen (N_xO) and ozone (O_3) are greenhouse gases that occur naturally in the atmosphere, though their composition could be altered by human influence. Others like *Hydrofluorocarbons* (HFCs), *Perfluorocarbons* (PFCs), and S*ulfur hexafluoride* (SF_6) result exclusively from human industrial processes. Greenhouse gases vary in their ability to absorb and hold heat in the atmosphere (Pidwirmy, 2006). HFCs and PFCs are the most heat-absorbent, but there are also wide differences between naturally occurring gases. For example, nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide, and methane absorbs 21 times more heat per molecule than carbon dioxide (West, 2008). Human activities like use of fossil fuel in automobiles, burning of wood and organic materials, animal rearing and other farming practices and landfill operations release greenhouse gases into the atmosphere. Some activities serve as precursors for other artificial greenhouse gases. All of the major greenhouse gases have increased in concentration since the beginning of the Industrial Revolution (about 1700 AD). The contribution (called radiative effect) to the greenhouse effect by a gas is affected by the characteristics of the gas, its abundance and the indirect effect it may cause. For example, on a molecule-for-molecule basis the direct radiative effects of methane is about 72 times stronger than carbon dioxide over a 20 year time frame but it is present in much smaller concentrations so that its total direct radiative effect is smaller and it also has a shorter atmospheric lifetime. On the other hand, in addition to its direct radiative impact methane has a large indirect radiative effect because it contributes to ozone formation (Houghton, 2005). While some GHG have shorter atmospheric lifetime ranging from few days to months (water vapour has atmospheric lifetime of about 9days whiles methane has few months) others like CO_2 can persist for 30-95 years (Jacobson, 2005). Carbon dioxide is however considered to be the most significant contributor to global warming because of its long atmospheric lifetime and also it is the most gas released to the atmosphere through human activities.



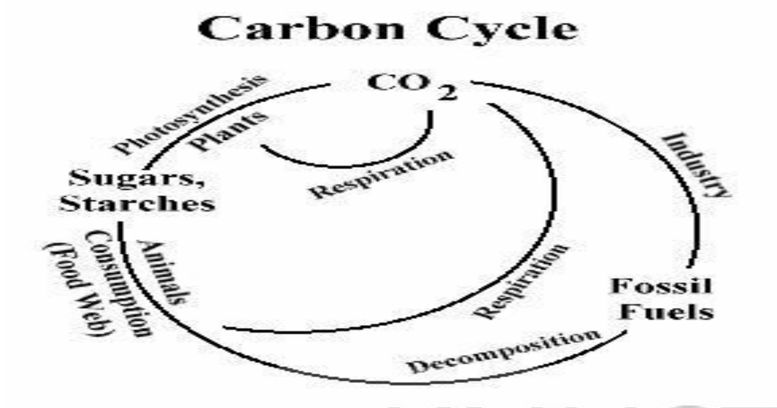
Source: http://www.weatherquestions.com/What_is_the_greenhouse_effect.htm

Figure 1: The Greenhouse Effect

2.3 The Carbon Cycle

Carbon is a chemical element with symbol C and atomic number of 6. As a member of group 14 on the periodic table, it is nonmetallic and tetravalent-making four electrons available to form covalent chemical bonds (http://www.chemicalelements.com/show/dateofdiscovery.html). Carbon is one of the few elements known since antiquity.The name "carbon" comes from Latin *carbo*, coal. Carbon sometimes is considered the element of life, since all living cells and organic molecules contain carbon (http://chemistry.about.com/).

Carbon cycle (Figure 2) is the movement of carbon, in its many forms, between the biosphere, atmosphere, oceans, and geosphere (http://www.cotf.edu/ete/modules/carbon/efcarbon.html). Green plants convert carbon dioxide to carbon through a process of photosynthesis. The carbon stored in plant tissues are released to animals and humans when eaten. Carbon is released back to the environment when plants and animals die. Fossil fuels which are formed from remains of dead organic matter also contain carbon. When fossil fuels and plants are burnt, they release considerable amount of carbon to the atmosphere.



Source: Henderson's Dictionary of Biological Terms, by Eleanor Lawrence. 10th Ed.

Figure 2: The Carbon Cycle

2.4 Effect of Climate Change on weather and various Ecosystems

Various ecosystems will experience changes as a result of changing climatic patterns and global warming. Ecosystems in different climatic zones will experience different changes. Some areas would experience detrimental effects while others experience beneficial effects from climate change. However, the number of areas or countries that would adversely be affected by climate change far outweighs those that would benefit from climate change. The obvious changes include rising sea levels, changes in amount and patterns of precipitation, extreme weather events (IPCC, 2007). Geographically restricted ecosystems are more potentially vulnerable to climate change. Examples include coral reefs, mangrove forests and other coastal wetlands, high mountain ecosystems (200-300m) and ecosystems overlying permafrost (Watson *et al.,* 2002)

2.4.1 Effect on weather

El nino southern oscillation (ENSO) which is a recurrent and normal oceanographic phenomenon that produces extreme weather conditions in many parts of the world has been more frequent, persistent and intense in many parts of the world since the mid 1970s compared with the previous 100 years. ENSO consistently affect regional variations of temperature and precipitation over much of the tropics, subtropics and some of the mid latitude areas (Woodrow Wilson National Fellowship Foundation, 1998). There have been higher maximum temperatures; more hot days and an increase in heat index, there have been higher minimum temperatures, fewer cold and frost days over nearly all land areas (Watson *el al.*, 2002). It has been observed that rainfall in the high and mid latitude of the northern hemisphere has intensified. Rainfall has generally declined in the tropics and subtropics of both hemispheres; when rain does fall, it is frequently so heavy that it causes erosion and flooding. Precipitation decreased in the twentieth century in the subtropics to about 3% while it increased to 5-10% in most mid and high latitudes of the northern hemisphere continents. Tropical cyclone intensity and precipitation rate would increase during the 21st century in the order of 5-10% and 20-30% respectively (Watson *et al.*, 2002). Over the next century, East Africa could receive more rain while southern Africa will probably become a great deal drier due to increase in evaporation (Töpfer, 2003).

"Increased summer drying and the associated risk of drought have been observed in a few continental areas, including Central Asia and the Sahel. Spatial and temporal patterns of precipitation have change over the years" (Töpfer, 2003).

2.4.2 Effect of Climate Change on Seas and Oceans

One significant effect of climate change on seas and oceans is sea level rise. As temperatures rise, the sea will absorb heat from the atmosphere, causing it to expand and therefore resulting in sea level rises. Recent studies show that the ice sheets in Greenland and Antarctica are melting faster than the snow is replacing the mass (Solomon *et al.*, 2007). Land glaciers will continue to melt over the coming century which will increase the level of the seas. The 4th Assessment Report the Intergovernmental Panel on Climate Change (IPCC) predicts a sea level rise of 0.18 – 0.38m increase by 2100 in the most optimistic scenario and 0.26 – 0.59m in the most pessimistic. Sea level rise and increases in storm surges associated with climate change will result in the erosion of shores and habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, and increased coastal flooding and, in turn, could increase the vulnerability of some coastal populations. It is projected that sea level rise will move from 0.09to 0.88m by the end of the 21st century (Watson *et al.*, 2002). IPCC technical paper V indicates that about 20% of the world's coastal wetlands could be lost by the year 2080 due to sea level rise. Reduction of sea ice in arctic and Atlanta could alter the seasonal distribution, geographic ranges, migration pattern, nutritional statues, reproduction success and ultimately abundance of marine mammals. Wetlands, such as mangroves, salt marshes and floodplains are generally more vulnerable to sea level rise since they are few meters below sea level (Solomon *et al.*, 2007).

Increasing CO_2 in seas causes acidification, brought about by increasing hydrogen ion concentration and thereby reducing the pH of the seawater. It has been indicated that oceanic pH has decreased by 0.1unit since the inception of the industrial revolution and it will drop by 0.3-0.5 units by the year 2100 as oceans absorb more CO_2 (Caldeira and Wickett, 2003; Orr *et al.* 2005).

Most plant and animals are decimating because of increased temperatures and pH of sea water. The tiniest marine plants and animals (zooplankton and phytoplankton) die off if water becomes too warm. It is projected that by the end of the 21st century, walruses, polar bears, seals and other marine mammals that rely on ice floes for resting, feeding and breeding will be particularly threatened (Töpfer, 2003). The warming of the north pacific ocean will compress the distribution of sockeye salmon (*Oncorhynchus nerka*) essentially squeezing them out of the north pacific into the Bering sea (Watson *et al.*, 2002). Climate change is likely to be a major threat to marine turtles given their life history characteristics, such as slow growth rate, and the potential influence of temperature on gender of embryos. Small increases in temperature may strongly bias the sex ratio of hatchlings towards females. Climate-related increases in wave energy and storm events may erode nesting beaches and reduce egg survival rates. Alteration of peak timing of egg laying has already been observe in Florida four loggerhead turtles. (CSIRO, 2005) .Corals has been disappearing at a rate of roughly 1% per year around the world. A 1% increase above the mean seasonal sea surface temperature causes coral bleaching while 3% increase causes extensive mortality of many corals (Mandia, 2010; Watson *et al.*, 2002). Increasing sea surface temperatures, together with other factors affect the health of many marine flora and fauna. Dermo and multinucleated disease in oysters have been correlated with El Niño events along the US Atlantic and Gulf Coast. Warmer sea surface temperatures are reducing upwelling and consequently the resupply of nutrients in the upper layers the ocean. The reduced amount of nutrients means less primary productivity by marine phytoplankton, which is critically important in the basic food chains of the ocean. For example, the least productive waters of the Pacific and Atlantic oceans have expanded by 6.6 million km^2 or by about 15.0% from 1998 through 2006 (Mandia, 2010). Some phytoplankton species cause emission of dimethyl sulfide to the atmosphere which has been link to the formation of cloud condensation nuclei. Changes in the abundance or distribution of such phytoplankton species may cause additional feedbacks on climate change (Watson *et al*., 2002).

2.4.3 Effect on fresh water (streams, lakes, rivers and ground water)

Studies reveal that, available total water in Africa's large catchment basins of Niger, Lake Chad and Senegal, has decreased by 40 - 60% (Töpfer, 2003). In large parts of Eastern Europe, European Russia, Central Canada and California, peak stream flows have advanced from spring to winter, since more precipitation falls as rain rather than snow, thus reaching rivers more rapidly than before. In many countries the consequences of less precipitation and more evaporation will put greater stress on freshwater supplies (Solomon *et al.*, 2007). Fresh water quality would also be impaired as there would be prolific growth of algae and water plants which are known to thrive well in warmer waters. As sea level rises, more salty water may eventually find its way into coastal aquifers and estuaries making them brackish and unsafe for human. Seawater intrusion will also affect the surface freshwater supplies of communities living within estuaries (Solomon *et al.*, 2007). Extreme water temperature can kill organisms while more moderate water temperature variations control biological processes such as physiological rates and habitat performance. However, temperature-dependent changes on lakes and streams will be least in the tropics, moderate in the mid latitudes and pronounced at the high latitudes where largest temperature changes are expected (Watson *et al.*, 2002). With projected climate warming, stream fish habitats are expected to reduce significantly across the United States for coldwater and cool water species. Some tropical species of zooplankton have reproductive temperature threshold close to the current temperatures and that their distributions are likely to be affected. Increased temperatures will affect thermal cycles of lake and solubility of oxygen and other materials and thus affect ecosystem function and structure (Watson *et al.*, 2002).

2.4.4 Effect on flora and fauna (Biodiversity) of terrestrial ecosystem

Many plants may respond positively to rising atmospheric concentrations of carbon dioxide, growing faster while using less water. Free Air Carbon Dioxide Enrichment (FACE) experiments are suggesting that forest net primary productivity, and thus carbon uptake, usually increases when atmospheric carbon dioxide levels increase, likely due to factors such as increased nitrogen use efficiency and competitive advantages of shade tolerant species. Increased temperatures are likely to increase respiration in many species due to a longer growing season, and drought stress will occur in stands lacking the soil moisture needed to support the increased respiration (Saxe *et al.*, 2001 cited in Covey and Orefice, 2009).

The threat of warmer climates causes concern that higher temperatures will negatively affect species that have adapted to historical climate patterns, leading to shifts in species composition. Higher temperatures, however, accelerate the evaporation of soil moisture and the decay of soil organic matter, leading to changes in the mix of nutrients. In many instances, these effects could slow plant growth while increasing their release of CO_2 into the atmosphere. Altered plant species composition especially, forbs and lichens have been observed in Tundra forest. It is asserted that climate change is more likely to affect vulnerable life stages such as seedling establishment but may not be enough to cause mortality in mature trees. Ecosystems with long live species will often be slow to exhibit changes and slow to recover from climate related stress. Forested ecosystems will be affected by climate change directly and via interactions with other factors such as land use changes (IPCC, 2007). Tropical forests are already experiencing an average temperature rise of 0.26^0C per decade since the 1970s (Malhi and Wright, 2004). The composition of forests is likely to change and new assemblages of species are likely to replace existing forest types (Watson *et al.*, 2002).

Since many species reproduce and survive within a narrow temperature range, most species would go extinct or will have to adapt to changing temperature ranges or would have to migrate to different locations for favourable temperature. Climate change is one of the threats that would put already 25% mammals and 12% birds into extinction in the next few decades (IPCC, 2007). Butterflies, dragonflies, moths, beetles and other insects are now living at higher latitudes and altitudes, where previously it was too cold for them to survive; migratory birds arrive earlier in the spring and depart later in the autumn, and many birds and amphibians are reproducing earlier (Töpfer, 2003). Species with limited climatic ranges and/or restricted habitat requirements and/or small populations are particularly vulnerable to extinction. Biota with temperature-dependent sex determination like sea turtle and crocodiles, amphibians with permeable skins and eggs could be more vulnerable. Changes in behavior, reduction in abundance or loss of species can lead to changes in structure and function of affected ecosystems. These changes can have a further loss of species and could have a cascading effect on biodiversity (Watson *et al.*, 2002;). Current and expected changes in temperature, precipitation, seas and increased frequency and intensity of extreme climatic events leading to climate variability will invariably affect biodiversity.

It is said that the Polar Regions are the key drivers of global weather patterns. Changes caused by global warming could cause these regions to magnify the greenhouse effect in a number of ways. For instance, warming dries out tundra which then dies and decomposes, giving off additional carbon dioxide (CO_2) and methane (CH_4).

2.4.5 Effects on human communities.

Climate change may affect food security but the effects are likely to be region specific (Parry *et al.*, 2007; Watson *et al.*, 2007). While some areas would experience a boom in food production because of increased precipitation and temperature and availability of land due to melting of glaciers, other would suffer severely from less rainfall, warmer high temperatures and increased evapotranspiration leading to shortage of food. In the tropics where rain-fed agriculture is practiced, even a minimal increase in temperature could significantly affect crop yield. Lobell *et al.* (2011) pointed out that, around Africa, temperatures above 30^{o}C in a day reduces the final yield of maize by 1% in an optimal rain-fed situation and 1.7% in drought situations. It has been observed that the growing season of controlled, mixed-species garden in Europe lengthened by 10.8 days from 1959 to 1993. Another study on trees and plants in the US showed that they are flowering earlier because of high spring temperatures. Species that serve as food for indigenous people and on which climate change impact will result in a reduced food source for people. For instance, populations of seal, marine birds, polar bears, tundra birds that will dwindle due to climate change are important food sources of indigenous people in the Arctic (Töpfer, 2003).

The World Health Organization –WHO (1948) defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”.

Climate change would virtually affect the physical and social well-being of people, especially, indigenous people as poverty and various diseases will increase.

The study by Töpfer (2003) found that diseases and troublesome invasive species are becoming more common, with many examples of diseases spreading rapidly as a result of warming conditions. Studies of the health impacts associated with climate variability (particularly those related to El Niño events) have provided new evidence of the sensitivity of human welfare and health to climate variability, particularly regarding vector- and water-borne diseases such as dengue and cholera. New patterns of heat waves and cold snaps, floods and droughts, and local pollution and allergens would affect health directly. Indirect effects will result from changes to ecological and social systems. Such impacts will include changes in infectious diseases, freshwater supplies, local food production, population movements and economic activities.

Predictions made by Töpfer (2003) indicates that if the current trend of global warming continues, by the end of the 21st century, various communities in the far north would be affected as permafrost thaw and causes terrain to subside resulting in damage to buildings, roads, pipelines and other infrastructure. Food and water shortages are likely to increase throughout most of Africa, over the next century. Water shortages could affect critically important food production. Conflicts over water, particularly in river and lake basins shared by more than one country, could well escalate and indeed as argues by Solomon (2010), that "the next world war would be fought over water and not oil". More frequent and intense storms, sun waves, floods, droughts and cyclones will also harm human health and could even lead to deaths especially among the elderly and the poor who are more vulnerable. These natural hazards can lead directly to death, injury and mental stress. Indirect effects would result from the loss of shelter, contamination of water supplies, reduced food supplies, heightened risk of infectious disease epidemics (such as diarrhea and respiratory disease), damage to health services infrastructure and the displacement of people. Climate change related catastrophes have increased fourfold since 1960 with its related increase in real cost of US$ 3.9 billion per year in 1950s as against US$ 40 billion per year in 1990s (Töpfer, 2003). Wildfires are expected to be pronounced in some areas because of drought and possibly, extensive growth of flammable fine fuel -small shrubs and grasses (Watson *et al.*, 2002). The populations of most pests are limited by low temperatures during parts of life cycle and climate change is expected to lead to more pests' outbreak in some regions. Shifts in the timing and ranges of wildlife species due to climate change could affect the culture and religious life of some indigenous people.

2.5 Mitigation and Adaptation

Parry *et al.,* 2007 in IPCC, 2007 defines mitigation as an "anthropogenic intervention to reduce net greenhouse gas emission that would lessen the pressure on natural and human system for climate changes". Mitigation options include reduction of greenhouse gas emissions through the reduction of fossil- fuel use, reduction of land-based emissions via conservation of existing large pools in ecosystems, and/or the increase in the rate of carbon uptake by ecosystems. Adaptation is also defined by the paper as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Natural and social systems would adapt spontaneously in response to climate change to a limited extent. However, such adaptation would not be sufficient for most regions.

In some cases advance planning can ensure that efforts to adapt achieve great benefits at low or even no cost (Parry *et al.*, 2007). The general effect of projected human induced climate change is that the habitat of many species will move upward from their current location (Watson *et al.,* 2002). There is the need for integrated approach to manage all ecosystems and human needs so as to reduce the impact of climate change. Some adaptation and mitigation measures includes forestry and related activities like reforestation, avoided deforestation and sustainable forest and land management, sustainable agricultural practices, fuel switching and efficient energy use at community level, use of biofuel, enhancing ecosystem resilience and its capacity to adjust to changes; education, awareness creation and dissemination of information. One other critical mitigation and adaptation measure is the advancement and development of science and technology (IPCC, 2007).

2.6 Carbon sequestration

The united Nations Framework Convention on Climate Change (UNFCCC) defines Carbon sequestration as 'The process of removing carbon from the atmosphere and depositing it in a reservoir. Carbon sequestration describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change (http://unfccc.int/essential_background/glossary/items/3666.php#C). It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels.

Carbon dioxide is naturally captured from the atmosphere through biological, chemical or physical processes. Some anthropogenic sequestration techniques exploit these natural processes, while some use entirely artificial processes. Biological carbon sequestration techniques include Forestry, Agriculture and peat production. Studies have highlighted the importance of terrestrial vegetation cover and associated dynamic feedbacks on the physical climate (Christesen *et al.*, 2007). An increase in vegetation density, for example has been suggested to result in a year-round cooling of 0.8^{0}C in the tropics, including tropical areas of Africa (Bounoua *et al.,* 2000)

2.6.1 Carbon Sinks

2.6.1.1 Seas and Oceans as carbon sink

The sea is the major store of carbon dioxide- about 50 times inorganic carbon in the sea compared to that of the atmosphere (NASA, 2003) and stores more than a quarter or about one third of anthropogenic emissions of CO_2 (Hance, 2009). Mandia (2010) asserts that through physicochemical and biological processes, the sea is able to accumulate and store atmospheric CO_2 for a length of time. While biological process is due to photosynthesis of marine plants and phytoplankton, the physicochemical process is due to solubility pump brought about by seawater temperature and thermocline circulation which together enables the sea to absorb and store CO_2. Solubility of CO_2 is inversely proportional to temperature. As CO_2 dissolves at the surface, circulation of the water takes CO_2 to lower depth where it is cooler and therefore favorable for CO_2 solubility and storage. High latitude, particularly the North Atlantic deep waters also store considerable CO_2 because of their low temperature (Mandia, 2010). A study conducted by Cox *et al.* (2000) predicted that the rate of oceanic CO_2 uptake will begin to saturate at a maximum rate at 5 gigatons of carbon per year by 2100 and indeed Khatiwala *et al*. (2009) has identified a 10% decrease in the oceans ability to sequester CO_2 since 2000.

2.6.2 Soil carbon

Carbon enters the terrestrial biosphere only through photosynthesis, and is shunted to the soil system by leaf- and debris-fall, the turnover (cycle of dead and new growth) of roots, and by the allocation of plant photosynthate to mycorrhizal fungi. Fine roots are the main source of carbon additions to soils, whether through root turnover or via exudates to associated mycorrhizal, fungi and the rhizosphere (Prince and Ashton, 2009). Roots and mycorrhizal fungi produce about half of total respired CO_2, with the balance from heterotrophic breakdown of organic matter. Prince and Ashton (2009) again asserts that, soil carbon dynamics vary from forest regions, depth and different soil orders with less information on tropical soils. They again indicates that, 'the global nature of the carbon cycle requires a globally-distributed and coordinated research program, but thus far research has been largely limited to the developed world, the top 30 cm of the soil profile, temperate biomes, and agricultural soils. Forest soils in tropical moist regions are represented by only a handful of studies and even fewer have examined sequestration of mineral carbon at depth'.

Plant residues are broken down by bacteria and saprophytic fungi, resulting in a cascade of complex organic carbon compounds that leach deeper into the soil. Carbon that leaves the forest soil system exits almost entirely via CO_2 respired by plants, bacteria and fungi. In general, soil carbon is strongly associated with rainfall distribution. In a synthesis of 42 studies from temperate forests, Michalzik *et al.* (2001) reported that precipitation was strongly positively correlated with the flux rate of dissolved organic carbon (DOC) from the forest floor into the mineral soil. The concentration of DOC in leachate from the forest floor to the mineral soil was positively correlated with pH, suggesting that more basic conditions favor microbial decomposition and thus DOC production. They also found that the greatest annual fluxes and greatest variability were in the lowest humified organic layer. DOC flux decreases with depth in the mineral soil. Soils carbon pool could be classified into labile and recalcitrant forms which decompose in varying degrees of time. Soil carbon can also exist in several forms with different degrees of protection from decomposition. The most stable form has turn over time of hundreds of years (Jandl *et al*., 2007). The extent of soil C retention in soils depends, among other things, on the nature of soil aggregation (Takimoto *et al.*, 2008). It can be short-term storage in macroaggregates (>250 μm diameter) and long-term storage in microaggregates (<250 μm diameter) including the widely accepted stability of C stored in the smallest size class, the silt and clay size fraction (<53 μm) (Six *et al.*, 2002).

It has been estimated that soils contain as much as four times carbon in vegetations (Prentice *et al*., 2001). Soils are the second after oceans in terms of carbon storage.

2.6.2.1 Soil carbon and land use management

Less disturbance of soil tends to preserve soil carbon stocks; and mixed species forests are more resilient and therefore better systems for securing carbon in forest soils. (Morris *et al*., 2007). Differences in plant anatomy lead to changes in the vertical distribution of minerals and soil carbon when there is land use or land cover change (Jackson *et al*., 2000). For example, in Fujian, China, conversion of natural forests to plantations has been linked to carbon loss (Yang *et al*., 2007).

In addition, during reforestation, soils are a slower but more persistent sink than aboveground carbon, and are more stable pools than aboveground pools for actively harvested forests (Thuille *et al*., 2000).

2.6.3 Forests and related forestry activities

Forests and other terrestrial ecosystems offer significant carbon sinks mitigation potential. Estimated global biological mitigation options is about 100 Gt for the year 2050 which is equivalent to 10-20% of projected fossil fuel emission during the same period. The largest biological potential is projected to be in the subtropics and the tropics (Dixon *et al*., 1994; Watson *et al*., 2002). Watson *et al*., (2002) further indicates that "the global mitigation potential of the post 1990 afforestation, reforestation and slowing deforestation activities is projected to be 60-87 Giga tonne on 700 million hectares between 1995 and 2050, with 70% in tropical forest, 25% in temperate forest and 5% in boreal forest. Afforestation, reforestation and avoided deforestation projects with appropriate management, selection criteria and involvement of local communities enhance conservation and sustainable use of resources. Mitigation efforts of climate change do not only reduce the impact of global warming but also seeks to reduce or eliminate deforestation and habitat loss of species. For instance, the tropical forest which houses about 50-70% of the world's terrestrial species currently experiences deforestation rate of 15 million ha of forest annually during the 1980s and accounted for about 1.6 Giga tons of CO_2 emissions. Mitigation potential of slowing rate of tropical forest deforestation has been estimated to be 11-21 Giga ton Carbon over 1995-2050 on 138Mega hectares.

Forest management activities can be used to sequester carbon in above and below ground and they include improved regeneration, fertilization, fire management, pest management, harvesting schedules and low-impact harvesting.

Watson *et al.* (2002) asserts that, deforestation and land clearing activities contributes to about a fifth of the greenhouse gas emissions during the 1990s with most being as a result of deforestation from tropical regions. A reduction in vegetative cover may lead to reduced precipitation at local and regional scales and change the frequency and persistence of drought. While all living plant matter absorbs CO_2 as part of photosynthesis, trees possess significantly more CO_2 than smaller plants due to their large size and extensive root system. Trees also thrive on lands longer than agriculture and small plants and therefore better sinks of carbon. According to the U.S. Department of Energy (DOE), tree species that grow quickly and live long are ideal carbon sinks. Unfortunately, these two attributes are usually mutually exclusive. Given the choice, foresters interested in maximizing the absorption and storage of CO_2 usually favors younger trees that grow more quickly than their older cohorts. However, slower growing trees can store much more carbon over their significantly longer lives (West, 2008).

As saplings develop into poles and then mature trees, increasingly large quantities of carbon are stored in the stem. This process has been demonstrated by a study in which entire eastern white pine trees in Ontario, Canada were destructively sampled; researchers found that mature 65 year old trees contained 69% of their total biomass in their stem while only 25% of total tree biomass was in the stems of 2 year old trees (Peichl and Arain, 2007, stated in Covey and Orefice, 2007). Mature trees will eventually sequester less and less carbon as they become larger due to physical growth limitations such as water stress (Whittaker *et al*., 1974).

2.6.4 Plantations

Although plantations have lower biodiversity than natural forest, they can reduce pressure from natural forest by serving as a source of forest products, thereby leaving greater area of natural forest for biodiversity and other environmental services. Optimal carbon sequestration could be achieved by planting fast growing species (Kelty, 2006). Ultimately, trees of any shape, size or genetic origin help absorb CO_2.

2.6.5 Agricultural lands

Activities and projects in the agricultural sector to reduce green house gas emissions and increase carbon sequestration can promote sustainable agriculture, promote rural development and may enhance or decrease biodiversity. A large number of agriculture management activities can be made to sequester carbon in soils and they include; intensification, conservation tillage, irrigation, fertilization, erosion control and rice management (Watson *et al*., 2002). Agroforestry activities can increase carbon storage on land where it replaces annual crops on degraded lands. Some agricultural practice such as fertilizer application and tillage practices can however serve as carbon source.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was carried out in a moist semi- deciduous tropical forest. Semi-deciduous forest ecosystem data was collected from Bobiri forest reserve which has an area of 5445 hectares, in southern Ghana (Hall and Swaine, 1981, Hawthorne and Abu-Juam 1995). The reserve lies between latitude 6^0 40’ and 6^0 44’ North of the Equator and longitudes 1^0 15’ and 1^0 22’ west of the Greenwich and falls under the Juaso Forest District of Ashanti Region. The forest reserve is divided into 73 compartments which are put under four designations based on their use namely; production, butterfly sanctuary, research and strict nature reserve. The compartments that fall under production is managed by Forest Services Division (FSD) of the Forestry Commission whiles those that fall under research, butterfly sanctuary and strict nature reserve is managed by Forestry Research Institute of Ghana (FORIG).

Farmland, teak plantation and fallow lands data were taken on the compound of Forestry Research Institute of Ghana (FORIG). FORIG is situated in a moist semi-deciduous forest. The two sites were separated by a distance of about 18km.

3.1.1 Climate

The area experiences bimodal rainfall with the major season occurring between April and July, while the minor season is from September to October with a dry season of three to four months, which is from December to mid-March. The mean annual rainfall is between 1500 and 1750 mm. Temperatures are uniformly high with 36.1^{o}C and 21.7^{o}C as the mean maximum and mean minimum, respectively. The maximum monthly average of 32.8^{o}C occurs in March while the minimum of 19.9^{o}C occurs in January. Relative humidity is in the range of 85%.

3.1.2 Topography and geology

The landscape is gently undulating with an elevation between 180 m and 245 m above-sea-level. The shallow valley is generally wet during rainy season and becomes flooded for brief periods. The Bobiri forest area falls within the forest dissect terrain region and is underlain by the pre-Cambrian rocks of the Birimian and Tarkwaian formations (Ejisu-Juaben Municipal Assembly, 2006). The area which is undulating has a number of smaller rivers one of which the Bobiri forest takes its root name from (Personal Communication with Chief of Kubease).

3.2 Data Collection

3.2.1 Plot design

The choice of sampling method depended on the type of data being collected. For forest ecosystem with different tiers of plants, nested plot design was used. This sought to reduce the error associated with lumping the treatments together as if they were the same. With this method, a different error variance for each different plot size is achieved which invariable reduces the overall error margin and increases precision (Crawley, 2005).

Quadrats were arranged to include frequency method used. Frequency is defined as the chance of finding a species in a particular area in a particular trial sample. This is obtained by using quadrats and it is expressed as the number of quadrats occupied by a given species per total number laid. Both shoots and roots frequencies were recorded. Similar sampling design was also used for collecting information about species composition, species dimension and edaphic factors.

Nested plot design was used for data collection in the natural forest because of the diverse life forms and differential sizes of trees. A simple randomized design was however used for the other land use systems.

Three Temporary Sample Plots (TSPs) of dimension 50 m x 50 m were randomly constructed in the natural forest. Each of the TSPs was subdivided into 25 m x 25 m. One of the 25 m x 25 m was randomly selected and 12.5 m x 12.5 m sub-subplot was constructed in it as shown in Fig. 3 The other land uses (farmland, fallow land and teak plantation) had a plot dimension of 20 m x20 m. 1 m x1 m quadrat were randomly laid around the four corners and the center of the plots. The treatment was replicated three times in all the land use types. The replicates were at least 30m apart.

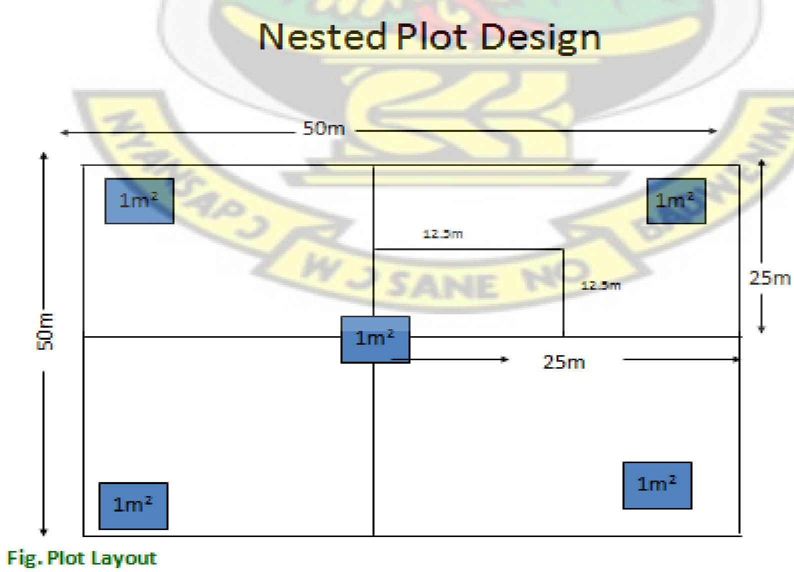


Figure 3: Nested Plot Design

Plate 1: Laying of Plots

3.2.2 Data on Vegetation

Diameters at breast height –dbh (at 1.3m) of trees greater than 2 meters in height were inventoried within the quadrats. Trees of dbh greater than 20cm were measured in the 50 m x 50 m plot of the natural forest (NF). Trees of dbh of 10-20 cm were inventoried in the 25 x 25 m subplot. Trees or saplings less than 10 cm were identified and measured in the 12.5 m^2 plot. Herbs, shrubs, twines and grasses were identified and destructively sampled from 1m^2quadrat around the center and four corners of the main plot. Fresh masses were immediately taken and samples put in sealed, well-labeled plastic bags for onward determination of dry mass in the laboratory. Litter was also collected in the 1 m x 1 m quadrant.

Dbh measurement of trees in the fallow, farm and teak lands were taken in a main plot of 20 m x 20 m. Other tree species found in the plantation were also identified and recorded. Two plots of the teak plantation were 13 years old (plots 1 and 2) with 3 m x3 m and 2 m x 6 m spacing respectively. The third plot was 11 years old and had planting distance of 1 m x 1m. Fallow land had been left untended for about 20 years.

Litter, shrubs, herbs and soil samples were taken in the 1 x1m quadrat.

3.2.2.1 Height measurement

Plant heights were obtained using clinometers. The instrument is held before the reading eye so that the scale can be read through the optics and the round side window faces to the left. The instrument is aimed at the object by raising or lowering until the hairline is sighted against the point to be measured. At the same time the position of the hairline against the scale gives the reading.

The triangulation (Pythagoras theorem) was then used to determine the height of trees (Beals *et al*., 2000). The length of the tree from the dbh level to the base of the tree was recorded. Likewise the distance from the dbh level to the tip of the tree. The distance from the dbh level to the first and second fork of the tree was also noted.

3.2.2.2 Diameter measurement

Caliper was used to measure the dbh at 1.3m (Fig. 2). Two dbh recordings were made, adjacent to each other and their averages represented the diameter of the respective tree.

Plate 2: Measuring DBH with caliper

3.3 Biomass and biomass carbon determination

Height and Dbh measurement were used to calculate tree phytomass of the plant species. The phytomass was determined using the following Allometric equation stated by (Henry *et al*., 2010).

1. $W_f = 0.00347 DBH^2 \times H \times \rho$
2. $Wt = 0.3158 \times V^{1.0806}$

Where

W_f	=	Biomass of forest, fallow and cropland (natural stands)
Wt	=	Biomass of teak stand
DBH	=	diameter at breast height
H	=	tree height
V	=	Predicted volume of teak
ρ	=	density

Value of below ground carbon was extrapolated using the formula below:

3. $W_b = \text{Exp}(-1.0587 + 0.8836 \times \text{LN } W_f \text{ or } W_t)$

Where

Wb = belowground biomass

Aboveground and belowground biomass was then converted to carbon by multiplying by 0.4748(47.48%) as stated by Adu-Bredu *et al*., 2008.

3.4 Shrubs and litter

After the determination of fresh weight of shrubs (including herbs, twines and saplings) and litter on the field, samples were brought to the laboratory in sealed plastic bags. Samples were put in envelopes and total fresh weights were determined before oven-drying at 65°C (Plates 3 and 4). Weight measurements were taken daily till samples attained constant weight.

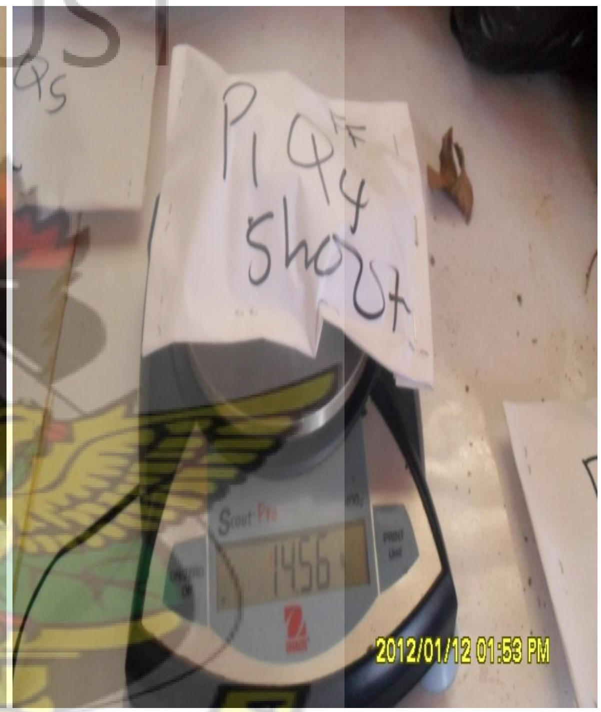


Plate 3: Stacking litter into envelopes **Plate 4: weighing shoot**

Total dry mass of samples was calculated using the formula as follows:

$T_{dm} = S_{dm}/S_{fm} \times T_{fm}$

Where

T_{dm} = Total dry mass

S_{dm} = Sample dry mass

S_{fm} = Sample fresh mass

T_{fm} = Total fresh mass

Carbon content is known to be 29.98% and 37.46% of total dry mass for litter and herbs respectively as stated by Adu-Bredu *et al.*, 2008. Total dry mass of litter and herb were thus multiplied by 0.2998 and 0.3746 for litter and herb respectively.

3.5 Soil samples

Soil samples were taken from five quadrats within each plot for all land-use types; Soils were sampled randomly from around the center and four corners of the plot. Soils were collected with a soil agar from different depths; 0-10cm, 10-20cm, 20-30cm and 30-40cm and air-dried (Plates 7 and 8). Samples were then sieved through a 2mm mesh to obtain fine grains for carbon analysis. Accompanying bulk density samples using soil core samplers were collected from the same soil depths (Plates 5 and 6). This enabled carbon contents to be expressed on an area basis and as well to assess the vertical distribution of soil C stock. The undisturbed soil samples were used for the bulk density determination.

The bulk density was determined from oven-dried core samples at 105^{o}C till constant weight. Soil C per hectare was calculated from the organic C content and the bulk density (Adu-Bredu *et al.*, 2008).

Plate 5: **Hammering core soil samplers into soil layers**

Plate 6: soil core sampler filled with soil

Plate 7: Soil Agar filled with soil analysis

Plate 8: Soil samples for organic carbon

3.5.1 Soil analysis

Soil organic carbon was obtained in the laboratory following the method of Walkley and Black (1934). Particle size distribution was also determined using Bouyoucos Hydrometer.

The Walkley and Black (1934) method involved a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid. After reaction the excess dichromate is titrated against ferrous sulphate (Plate 8). One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank (control) were included. 10mm of 1.0 Nitrogen (equivalents to 1667 Mole) potassium dichromate solution was added to the soil and the blank flask. To this 20ml of concentrated sulphroric acid was carefully added from a measuring cylinder swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250ml) and concentrated orthophrophoric acid (10.0ml) were added and allowed to cool. One milliliter of dipherylamine indicator was added and titrated with 1.0M ferrous sulphate solution.

Calculation

The organic carbon content of the soil was obtained as follows:

$$\text{Percentage organic carbon} = \frac{M \times 0.39 \times (V1-V2)}{S}$$

Where

M= Molarity of ferrous Sulphate solution

V1=Volume of Ferrous Sulphate solution required for blank

V2= Volume of ferrous sulphate solution required for sample

S= Weight of air-dry sample in 0.39=3x0.001x100% x1.3 (3= equivalent weight C)

1.3= Compensation factor for the incomplete combustion of the organic matter.

Plate 7: Titrating soil solution against ferrous sulphate

3.5.2 Bulk Density Determination

Undisturbed core soil samples that were taken were oven dried after net fresh weight were taken. Samples were dried at a temperature of 105°C and daily readings were recorded till samples attained constant weight.

Samples were then cooled to room temperature and sieved through a 2mm mesh (Plate 9). Coarse and fine textures of each sample were thus separated. Volumes of coarse and fine samples were obtained by the use of water displacement method; samples were put in small, transparent plastic bags then submerged in a predetermined water level in a measuring cylinder of which the rise in water level recorded as the volume of the sample (Plate 10).

Bulk density was calculated using the following formula:

$$BD = St/(Sv - [Sf/Rd\ ])$$

Where:

BD	=	Bulk density
St	=	Total mass of soil
Sv	=	core sample volume (volume of cylinder used to collect soil)
Sf	=	mass of fine soil
Rd	=	rock density (mass of coarse soil sample÷ volume of coarse soil)

Plate 8: Sieving soil to separate Coarse particles

Plate 9: immersed soil displacing volume of water

3.6 Relative Frequency and Relative Density

The relative frequency/density of the various species was determined for the plots in the different land use systems. Formulae employed for the calculations are stated below:

Relative frequency = $a/b \times 100$

Where a =frequency of individual species
b = sum of frequencies of species within a habitat

$$\boxed{H' = -\Sigma\, \rho \ \text{In}\ \rho}$$

Where,
ρ = proportion of species in the sample plot

In ρ = natural of ρ
H'=Shannon diversity

High values of H would be representative of more diverse communities. A community with only one species would have an H value of 0. If the species are evenly distributed then the H value would be high.

3.7 Data Analysis

Data was analyzed with Microsoft Excel (2007) after it has been inputted into the spread. Data was sorted and filtered to make computation easy. The pivot table in Excel helped to summarize data effectively. Comparisons of means were also done using the Analysis of Variance (ANOVA) package in Excel. Significance level at 95% was used to assess the significance between and within treatments.

CHAPTER FOUR

4.0 RESULTS

The primary productivity of a community is the rate at which biomass is produced per unit area by plants which are the primary producers. It can be expressed either in units of energy (e.g. Joules m^{-2} day^{-1} or dry organic matter (eg. Kg ha^{-1} $year^{-1}$). The total fixation energy by photosynthesis is referred to as gross primary productivity (GPP). A proportion of this is respired away by the plant itself and is lost from the community as respiratory heat (R). The difference between GPP and R is known as net primary productivity (NPP) and represents the actual rate of production of new biomass that is available for consumption by heterotrophic organisms (Begon *et al.*, 1990). Biomass was thus converted to carbon by multiplying biomass by predetermined carbon content values of trees, litter and shrubs.

4.1 Tree Biomass Carbon

Results of amount of carbon stored in trees of the various land use system are presented in Table 1. Tree carbon was high in natural forest followed by plantation. Fallow and cropland land had the least tree carbon.

Table 1: The amount of Carbon produced by aboveground vegetation

Replicate	Value	Cropland	Fallow	Plantation	Forest
X ±SD		(Mg C ha^{-1})			
1	Sum	0.0023	2.90	161.40	265.51
	SD	7 x10^{-5}	0.06	0.55	9.61
2	Sum	0.02	5.61	179.65	111.06
	SD	3.1 x 10^{-3}	0.06	0.06	6.83
3	Sum	1.38	4.31	97.02	257.77
	SD	0	0.05	0.18	8.46

Analysis of Variance

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12496.25	2	6248.12	0.6412	0.5593	5.1433
Columns	392496.3	3	130832.1	13.4273	0.0045	4.7570
Error	58462.29	6	9743.71			
Total	463454.9	11				

4.2 Belowground Carbon

Table 2 gives the below ground carbon which is a function of the above ground carbon. Below ground carbon also decreased from natural forest, teak plantation, fallow land and cropland respectively.

Table 2: Amount of belowground carbon of the different land use systems

Replicate	Values	Cropland	Fallow	Teak	Forest
X ±SD			Mg C ha^{-1}		
1	Sum	0.0011	0.6662	27.5613	35.70
1	SD	7.58×10^{-5}	0.0603	0.5454	0.49
2	Sum	0.0071	1.2352	30.8384	16.29
2	SD	0.0031	0.0594	0.4379	0.36
3	Sum	0.2747	1.0193	19.2486	34.19
3	SD	0	0.0522	0.1822	0.46

Analysis of variance

Source ofVariation	SS	df	MS	F	P-value	F crit
Rows	30.62	2	15.312	0.33	0.73	5.14
Columns	2163.20	3	721.07	15.78	0.003	4.75
Error	274.25	6	45.71			
Total	2468.08	11				

4.3 Litter Carbon

Results of carbon content of the litter component of the different land use systems are presented in table 3. Teak plantation had the most litter carbon followed by fallow land, natural forest and cropland land respectively.

Table 3: The amount of Carbon produced by Litter

Replicate	Values	Cropland	Fallow	Plantation	Forest
X ±SD		(Mg C ha^{-1})			
1	Mean	0.56	1.60	2.48	1.18
	SD	0.91	0.57	0.51	0.88
2	Mean	0.28	1.54	2.22	1.04
	SD	0.11	0.41	0.37	0.69
3	Mean	0.58	1.87	1.95	0.82
	SD	0.39	1.02	0.23	0.48

Analysis of Variance

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.059596	2	0.029798	0.59556	0.593742	6.944272
Columns	4.786587	2	2.393294	47.8339	0.001611	6.944272
Error	0.200134	4	0.050033			
Total	5.046317	8				

4.4 Herb Carbon

Table 4 indicates the carbon content of herbs of the different land use systems. Herb carbon increased from teak plantation, natural forest, and fallow land to cropland.

Table 4: The amount of Carbon produced by herb layer of various ecosystems

Replicates	Values	Cropland	Fallow	Plantation	Forest
X ±SD		(Mg C ha^{-1})			
1	Mean	0.51	0.16	0.06	0.08
	SD	0.28	0.12	0.05	0.07
2	Mean	0.37	0.21	0.08	0.03
	SD	0.24	0.25	0.09	0.02
3	Mean	0.16	0.44	0.16	0.03
	SD	0.08	0.61	0.23	0.02

Analysis of Variance

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.00222	2	0.00111	0.058368	0.943832	5.143253
Columns	0.174676	3	0.058225	3.061922	0.113021	4.757063
Error	0.114095	6	0.019016			
Total	0.290991	11				

4.5 Soil Bulk Density

Soil bulk density values are presented in table 5. Soil bulk density increases along the soil horizons, from topsoil to the 40cm depth for all the land use systems. Generally, bulk density was highest in teak plantation but the increase along soil horizons was not definite among the other land uses (Natural forest, fallow and croplands).

Table 5: Bulk density of Soils of the different land use types

	Values	Cropland	Fallow	Plantation	Forest
X ±SD		(g/dm^3)			
Horizon	**0-10**	0.37	0.34	0.66	0.34
	10-20	0.38	0.40	0.83	0.43
	20-30	0.44	0.45	1.03	0.44
	30-40	0.48	0.57	1.27	0.47

4.6 Soil Carbon stock

Soil carbon stock with respect to the soil horizons decreased with increasing depth for all the land uses as depicted in Table 5. Soil carbon stock was however highest in natural forest, followed by cropland, fallow land and teak plantation had the least.

Table 6: Soil Carbon stock soils of the various land use types across different soil horizons

	Horizon	Cropland	Fallow	Plantation	Forest
X ±SD		($MgCha^{-1}$)			
	0-10	8.32	5.09	4.75	9.89
	10-20	5.71	5.01	3.69	9.74
	20-30	3.78	3.84	3.68	8.06
	30-40	1.91	3.58	2.68	4.28

Analysis of Variance

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	33.85	3	11.28	7.75	0.007	3.86
Columns	43.13	3	14.38	9.87	0.003	3.86
Error	13.10	9	1.46			
Total	90.09	15				

4.7 Total Carbon stock

Total carbon stock, which is the sum of all the five carbon pools (trees, litter, herbs, belowground and soil), was highest in natural forest, followed by teak plantation. Fallow land had a marginal increase in total carbon compared to cropland which had the least. Contribution of tree component to total carbon was pronounced in natural forest and teak plantation than the other two land use systems. Contribution of soil component was also high in natural forest and also significant in cropland (19.72 Mg C ha^{-1}) and fallow land (17.53 Mg C ha^{-1}) with teak plantation having the least contribution of soil carbon (14.81 Mg C ha^{-1}).

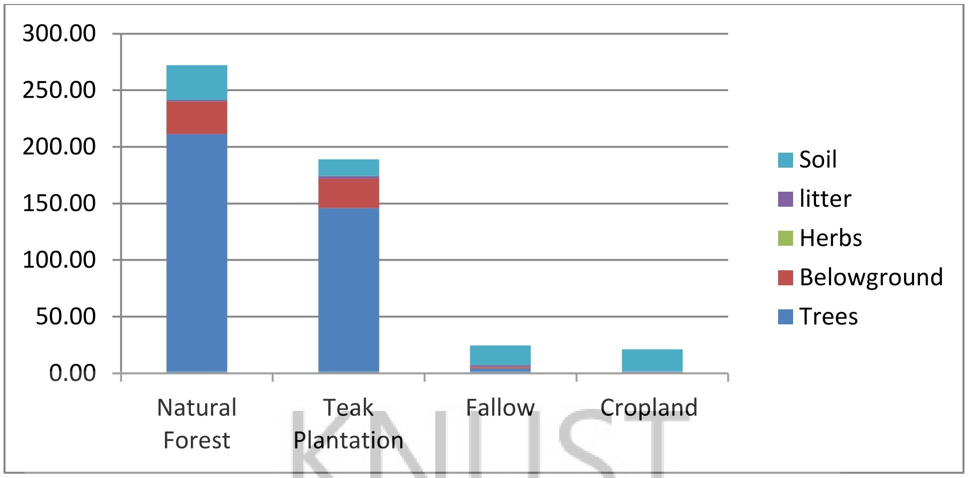


Figure 4: Contribution to total carbon by the various components

Table 7: Percentage Carbon of various pools of the different land use types

Land use	Aboveground	Belowground	Herbs	Litter	Soil
Forest	40.68	5.63	0.01	0.17	6.41
Teak P	29.28	5.19	0.02	0.44	2.97
Fallow	0.86	0.20	0.05	0.33	3.51
Cropland	0.09	0.02	0.07	0.09	3.96
Sum	**70.91**	**11.04**	**0.15**	**1.03**	**16.85**

4.8 Emission factor

Table 8 shows the amount of CO_2 emitted using natural forest as a standard. There was almost 100% emission in fallow and cropland with regards to trees and belowground carbon. There was however carbon gains in the case of herbs and litter carbon for all the three land use systems except for crop litter carbon where there was emitted carbon to the tune of 45.12%.

Soil C emission ranged from 53.67%, 45.17% and 38.3% for teak plantation, fallow land and cropland respectively.

Table 8: Emission factor of various pools when converted from Natural Forest to other land use

Landuse	Aboveground	Belowground	Herbs	Litter	Soil	Total C
Forest	0	0	0	0	0	0
Teak	-0.28	-0.08	1.50	1.58	-0.54	-0.28
Fallow	-0.98	-0.96	5.75	0.94	-0.45	-0.91
Cropland	-0.99	-0.99	7.75	-0.45	-0.38	-0.92

4.9 Removal Factor

Table 9 shows the removal factor of converting natural forest, fallow land and cropland to teak plantation. While there was removal of CO_2 from the atmosphere in the case of cropland and fallow land, natural forest conversion to teak plantation results in emission of CO_2.Table 9: Removal factor of various pools when various land use types are converted to Teak Plantation

Landuse	Aboveground	Belowground	Herbs	Litter	Soil	Total C
Forest	-0.28	-0.08	1.5	1.58	-0.54	-0.28
Teak	0	0	0	0	0	0
Fallow	33.2	25.68	-0.63	0.33	-0.16	6.65
Cropland	309.68	286.56	-0.71	3.72	-0.25	7.96

4.9 Diversity of the Stand

Table 10: Number of Species and Families in the various land use types

Land use	No. of Species	No. of Families	No. of stems	H'
Forest	88	36	490	3.83
Fallow	14	7	50	2.26
Cropland	5	5	8	1.49
Plantation	3	3	226	0.20

4.9.2 Relative Frequency

Relative abundance of the various species is presented in Appendix II. *Cleidion gabonicum* obtained the highest relative abundance (20.72%) in Plot 3 of natural forest. Teak plantation had a few of other species like *Ficus exasperata* and *Alsonia Broonii* in Plots 1 and 2 but none in plot 3.

CHAPTER FIVE

5.0 DISCUSSION

Biomass is a manifestation of net production. Since all plant species do not have the same metabolic rates their production will be different within the plant community. The difference will also be influenced by the age of the different plants, their leaf area and the seasonal changes. Knowledge of biomass production rates gives us a clue to the performance of a species within a community. Species which possess more biomass and have higher production rate will dominate the community. In the present study the biomass expressed as carbon production rate was not uniformly distributed; much of the CO_2 sequestration occurred in the forest ecosystem.

5.1 Tree Biomass Carbon

Increased tree biomass carbon in natural forest is expected since there were more trees with large boles in natural forest. Teak trees were quite many but had small diameters which accounted for relatively low carbon. Amount of carbon in trees is influenced by the density and size of tree (Brown *et al.*, 1989). As indicated by Covey and Orefice (2009), carbon stored in trees increases as saplings develop into poles and then matures trees. Stand level carbon stocks in the form of biomass and coarse woody material increase as a stand progresses through succession stages (Odum, 1969; Whittaker *et al*., 1974).

The total number of teak tree were 226 with average dbh of 12.9cm whiles natural forest and fallow land trees numbered 49 and 50 with average dbh of 16.5 and 20.5 respectively. Covey and Orefice (2009) states that: 'half of all carbon dioxide absorbed by forests is used for respiration and maintenance and the remainder stored as biomasses.

Tree phytomass carbon of 211.45 Mg C $ha^{-1}$of natural forest in this study is comparable to that of moist evergreen forest of Ghana value of 202.07 as stated by Adu-Bredu *et al*. (2008), and 204.0 Mg C ha^{-1} given by Koto-Same *et al.* (1997) for six different sites in the humid forest zone of Cameroun.

It could be realized that the third plot of the teak plantation had more stems than the other two plots (Appendix 1) but the total carbon was small compared to the other two plots. This is attributed to the close spacing of the third plot; 1 x 1 m, compared to 3 x 3 m and 2 x 6 m of the other two plots. The age difference accounted for the low volume of the third plot as Mean annual increment (MAI) are 12.4, 13.8 and 8.8$m^3ha^{-1}yr^{-1}$ for plots 1, 2 and 3 respectively. Significance level at P = 0.05 however, showed no significant difference among the plots. Meanwhile, there was significant difference among the different land use systems with respect to tree carbon.

5.2 Herb and litter carbon

The much litter carbon associated with Teak plantation is attributable to the broader leaves that are shed periodically. Teak leaves are much lignified and takes longer time to decompose (Chanakya *et al*., 2009). There were few trees on the cropland which sheds few leaves. Litter carbon for the various land use systems was significantly different at 95% confidence interval.

The low herbaceous carbon in natural forest and teak plantation may be attributed to the dense canopy which does not favour undergrowth due to reduced sunlight reaching the forest floor (Djabletey and Adu-Bredu, 2007). Differences in amount of herbaceous carbon was however not statistically different ($P > 0.05$).

5.3 Soil Carbon stock

Decrease in carbon stock with increasing depth might be as a result of humus and microbial activity that reside at the topsoil (Michalzik *et al*., 2001, Murty *et al*., 2002)

The low soil carbon stock of teak can be attributed to the slow decomposing broad leaves (Adu-Bredu *et al.*, 2008) which are characterized by relatively high lignin or cellulose content.

Climate, soil type and vegetation usually act together to influence the soil content of organic carbon (Nacro *et al*., 2008) Soil carbon stock is controlled by climate, vegetation, topography, parent material, time and management (Jenny 1980).

The study confirms that whenever the forest is intact, the potential to sequester organic carbon is always high. Once the forest is converted to different land uses through vegetation removal, decarboxylation processes set in to reduce soil organic carbon with accompanying CO_2 emissions (Bonsu *et al*., 2008).

5.4 Total Carbon Stock

The high total carbon stock of natural forest is an indication that natural forest sequesters considerable amount of CO_2 and thus reduce global warming. As asserts by IPCC (2007) "a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber fibre or energy from the forest, will generate the largest sustained mitigation benefit". Trees and soils of forests sequestered considerable carbon (40.7% and 6.4% respectively). Plantations also sequester greater amount of CO_2 and therefore serve as an alternative to natural forest in terms of terrestrial carbon sink. Natural forests, together with plantations can help mitigate climate change in addition to their numerous ecological and economic benefits. In this study natural forest together and teak plantation sequestered about 90.81% of carbon.

5.5 Emission and Removal Factor

Emission and removal factor helps us generate the activity data for given land use at a specified location. For instance, the removal and emission factor shown by this experiment could be used to calculate the CO_2 removal or emission for a specified land use type of an area in a moist semi deciduous ecological zone (http://unfccc.int/ghg_data/online_help/definitions/items/3817.php)

CO_2 emissions due to conversion of natural forest to other land uses were evident in this study. Teak plantations planted extensively in the tropics could be considered a better means of CO_2 sequestration because it emits less CO_2 than the other land use systems. When degraded lands are left to fallow in other to serve as carbon sink, its contribution is minimal compared to teak plantation. Bonsu *et al*., 2008 asserts that, instead of leaving land under bush fallow to regenerate naturally, reforestation should be done using fast growing leguminous trees in order to achieve maximum carbon sequestration potential of the land. It is important to note that degradation of soil organic carbon becomes more serious because of the slow process of natural fertility restoration. This is due to the fact that most tropical soils are not resilient, that is, their ability to return to their formal condition after stress is very weak (Lal, 1994). Converting natural forest to cropland is seen to emit huge amounts of CO_2 to the atmosphere either through clear-felling the area or slash and burn which is associated with farming in Ghana. The much less difference between soil C in fallow land and cropland is confirmed by Bonsu *et al*., 2008 who states that: "Although it is commonly accepted that fallow will increase soil C content, and influence soil physical and biological properties in a favourable way for plant production and crop growth, many authors found no significant changes of soil carbon content after cultivation".

Slash and burn agriculture often practiced in Ghana, leaves land entirely without trees. Trees on agricultural lands are seen as a threat to increased crop productions. This method, however, reduces the ability of agricultural lands to sequester carbon.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

Conclusion

The study showed that natural forest sequesters significantly more carbon than the rest of the other land use systems. This was followed by Teak plantation, fallow land and cropland in descending magnitude of total carbon stock. Soils of the different land use systems do not contain the same amounts of carbon.

Natural forest had much soil carbon, followed by cropland, fallow land and teak plantation respectively. The differences were significant statistically.

Aboveground had significantly much more carbon than the other four pools. Soils, belowground, litter and herbs had decreasing amounts of carbon.

When natural forest is converted to Teak plantation, fallow land or cropland, there is associated emission of CO_2 but Teak plantation emits less CO_2, (-0.28) followed by fallow (-0.91) land and cropland (-0.92). There is removal of CO_2 from the atmosphere when cropland or fallow land is converted to Teak plantation. Conversion of natural forest to teak plantation however results in emission of CO_2.

6.2 Recommendations

It is recommended that:

1. Land management options aimed at carbon sequestration should involve enhancement of natural forest through prudent silvicultural practices or establishment of plantations. Fallow lands and croplands geared towards carbon sequestration should

incorporate activities that increase the soil carbon. For instance no tillage and cultivation of leguminous plants.

2. Agroforestry should be encouraged as a means of ensuring food security and enhancement of carbon sequestration as trees sequester a reasonable amount of carbon dioxide.
3. Improved fallow is recommended as opposed to natural fallow. This is because, even a 13-year old teak plantation performed better in terms of carbon sequestration than over 20-year old fallow land.
4. The two other carbon pools (belowground and dead wood) of the land use systems should be investigated into. Belowground values in this experiment were function of the aboveground values. Experiments should rather be carried out to assess the belowground carbon.

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APPENDICES

Notes on statistical methods used

Statistical evaluation of the difference between pairs of means was generally based on analysis of variance. The complete analysis of variance table is too cumbersome and can be substantially reduced without losing any of the information embodied (Yeboah-Gyan, pers.comm.). If values for variance–ratio (V-R) and residual mean square (RMS) are known, the complete table may be reduced as follows:

MS (Mean square) = V-R * RMS

SS (Sum of Squares) = MS*df (degrees of freedom).

The total sum of squares (SS) is found by summation of the above values

Appendix I

Total carbon of various components (liiter, herb, trees, soil) of the different landuse systems

Land use	Replicate	Trees	Belowground	Herbs	litter	Soil (0-20)	Soil (20-40)	Soil	Total CS
Natural Forest	1	559.20	35.70	0.08	1.18	13.07	7.87	20.93	617.10
	2	233.91	16.29	0.03	1.04	21.70	19.11	40.80	292.07
	3	542.89	34.19	0.03	0.82	16.01	14.97	30.98	608.91
	4	372.83	26.19	0.03	0.41	21.02	14.12	35.14	434.59
Mean		**202.87**	**28.09**	**0.04**	**0.86**	**17.95**	**14.01**	**31.96**	**263.80**
	1	161.40	27.56	0.06	2.48	10.75	8.23	18.98	210.49
Teak Plantation	2	179.65	30.84	0.08	2.22	5.45	5.35	10.80	223.59
	3	97.02	19.25	0.16	1.95	9.09	5.55	14.64	133.02
Mean		**146.02**	**25.88**	**0.10**	**2.22**	**8.43**	**6.38**	**14.81**	**189.03**
	1	2.90	0.67	0.16	1.60	12.96	10.97	23.93	29.26
Fallow	2	5.61	1.02	0.21	1.54	7.42	5.25	12.67	21.05
	3	4.31	1.24	0.44	1.87	9.92	6.06	15.98	23.83
Mean		**4.27**	**0.97**	**0.27**	**1.67**	**10.10**	**7.43**	**17.53**	**24.71**
	1	0.00	0.00	0.51	0.56	17.75	7.31	25.06	26.13
Cropland	2	0.02	0.01	0.37	0.28	12.51	4.93	17.44	18.12
	3	1.38	0.27	0.16	0.58	11.85	4.82	16.66	19.06
Mean		**0.47**	**0.09**	**0.35**	**0.47**	**14.04**	**5.69**	**19.72**	**21.10**

Appendix II
List of tree species in Natural Forest

Land use Type	Plot No.	Species Name	Frequency	Average Diameter	Density	Family	*Star Rating
Natural Forest	**1**	*Albizia ferruginea*	1	22	0.706	Mimosaceae	Scarlet
		Albizia glaberrima	1	29.00	0.545	Mimosaceae	Green
		Albizia zygia	2	33.65	0.49	Mimosaceae	Green
		Alstonia boonei	2	27.55	0.416	Apocynaceae	Green
		Antiaris toxicaria	1	1.60	0.43	Moraceae	Pink
		Baphia nitida	8	2.29	0.559	Papilionaceae	Green
		Blighia sapida	1	13.7	0.762	Sapindaceae	Green
		Blighia unijugata	1	35	0.508	Sapindaceae	Green
		Bussea occidentalis	5	22.22	0.792	Caesalpiniaceae	Green
		Ceiba pentandra	1	21.00	0.32	Bombacaceae	Green
		Celtis adolfi-friderici	2	20.40	0.581	Ulmaceae	Green
		Celtis mildbraedii	1	13.40	0.59	Ulmaceae	Green
		Celtis wightii	1	1.50	0.61	Ulmaceae	Green
		Celtis zenkeri	21	21.57	0.61	Ulmaceae	Green
		Cleidion gabonicum	10	3.17	0.64	Euphorbiaceae	Green
		Cleistopholis patens	1	18.3	0.36	Annonaceae	Green
		Cola nitida	1	28.00	0.58	Sterculiaceae	Pink
		Daniellia ogea	1	23.00	0.507	Caesalpiniaceae	Pink
		Distemonanthus benthamianus	2	17.75	0.67	Caesalpiniaceae	Pink
		Entandrophragma angolense	3	20.00	0.54	Meliaceae	Red
		Entandrophragma candollei	1	29	0.632	Meliaceae	Scarlet
		Entandrophragma cylindricum	1	14.20	0.624	Meliaceae	Scarlet
		Ficus capensis	1	16.7	0.4	Moraceae	Green
		Funtumia elastica	3	17.67	0.51	Apocynaceae	Pink
		Griffonia simplicifolia	1	3.2		Caesalpiniaceae	Green

		Hannoa klaineana	1	20.1	0.64	Simaroubaceae	Green
		Hymenostegia afzelii	14	19.34	0.824	Caesalpiniaceae	Green
		Hypselodelphys poggeana	5	2.00		Marantaceae	Green
		Khaya ivorensis	1	1.5	0.444	Meliaceae	Scarlet
		Klainedoxa gabonensis	1	25.2	0.926	Irvinginiaceae	Green
		Lannea welwitschii	1	20.0	0.45	Anacardiaceae	Green
		Microdesmis puberula	4	4.25	0.64	Pandaceae	Green
		Napoleonaea vogelii	1	2.00	0.69	Lecythidaceae	Green
		Nesogordonia papaverifera	3	41.90	0.74	Sterculiaceae	Pink
		Petersianthus macrocarpus	1	85.90	0.45	Lecythidaceae	Green
		Piptadeniastrum africanum	2	28.35	0.717	Mimosaceae	Pink
		Pycnanthus angolensis	1	13.50	0.652	Myristicaceae	Pink
		Rinorea oblongifolia	1	1.20	0.64	Violaceae	Green
		Spathodea campanulata	1	15.7	0.232	Bignoniaceae	Green
		Sterculia oblonga	3	54.20	0.582	Sterculiaceae	Green
		Sterculia rhinopetala	4	28.70	0.768	Sterculiaceae	Pink
		Strombosia glaucescens	3	1.33	0.896	Olacaceae	Green
		Terminalia superba	1	78.00	0.56	Combretaceae	Pink
		Trichilia monadelpha	1	20.00	0.481	Meliaceae	Green
		Trichilia prieuriana	8	11.34	0.63	Meliaceae	Green
		Triplochiton scleroxylon	2	104.65	0.384	Sterculiaceae	Scarlet
		Turraeanthus africanus	3	28.00	0.56	Meliaceae	Pink
		Xylia evansii	1	1.50	0.64	Mimosaceae	Blue
	2	*Acacia pennata*	4	3.08		Leguminosae	Green
		Alafia baterii	4	1.63		Apocynceae	Green
		Albizia adianthifolia	1	24.5	0.51	Mimosaceae	Green
		Alchornea cordifolia	1	5.00	0.64	Euphorbiaceae	Green
		Baphia nitida	12	2.47	0.559	Papilionaceae	Green
		Blighia sapida	1	11.5	0.762	Sapindaceae	Green
		Bussea occidentalis	1	25.6	0.792	Caesalpiniaceae	Green
		Celtis mildbraedii	1	5.00	0.59	Ulmaceae	Green
		Celtis wightii	3	16.07	0.61	Ulmaceae	Green

		Celtis zenkeri	8	24.63	0.61	Ulmaceae	Green
		Cola nitida	1	0.5	0.58	Sterculiaceae	Pink
		Craterispermum caudatum	1	1.5	0.64	Rubiaceae	Green
		Cylicodiscus gabunensis	1	23.0	0.941	Mimosaceae	Blue
		Elaeis guineensis	3	27.17	0.64	Palmae	Pink
		Entandrophragma cylindricum	1	35.60	0.624	Meliaceae	Scarlet
		Ficus capensis	4	11.75	0.4	Moraceae	Green
		Ficus exasperata	1	11	0.442	Moraceae	Green
		Funtumia elastica	5	9.32	0.51	Apocynaceae	Pink
		Glyphaea brevis	1	14.8	0.64	Tiliaceae	Green
		Griffonia simplicifolia	1	3.5		Caesalpiniaceae	Green
		Hannoa klaineana	1	27.6	0.64	Simaroubaceae	Green
		Hymenostegia afzelii	3	18.53	0.824	Caesalpiniaceae	Green
		Hypselodelphys poggeana	1	1.00		Marantaceae	Green
		Khaya ivorensis	2	14.5	0.444	Meliaceae	Scarlet
		Lannea welwitschii	2	21.15	0.45	Anacardiaceae	Green
		Macaranga hurifolia	1	2.4	0.4	Euphorbiaceae	Green
		Microdesmis puberula	1	2.3	0.64	Pandaceae	Green
		Motandra guineensis	2	1.75		Apocynaceae	Green
		Napoleonaea vogelii	1	1.0	0.69	Lecythidaceae	Green
		Nesogordonia papaverifera	2	16.00	0.74	Sterculiaceae	Pink
		Phyllanthus muellerianus	7	2.87		Euphorbiaceae	Green
		Piptadeniastrum africanum	2	73.00	0.717	Mimosaceae	Pink
		Pycnanthus angolensis	1	13.5	0.652	Myristicaceae	Pink
		Ricinodendron heudelotii	1	21.00	0.26	Euphorbiaceae	Green
		Sterculia rhinopetala	6	22.87	0.768	Sterculiaceae	Pink
		Strombosia glaucescens	3	13.47	0.896	Olacaceae	Green
		Tetrapleura tetraptera	1	7.00	0.5	Mimosaceae	Green
		Trichilia prieuriana	3	4.00	0.63	Meliaceae	Green
		Trilepisium madagascariense	2	44.35	0.52	Moraceae	Green
		Triplochiton scleroxylon	3	20.8	0.384	Sterculiaceae	scarlet
		Zanthoxylum gilletii	1	23.00	0.81	Rutaceae	Green

	3	*Alafia baterii*	2	2.65		Apocynceae	Green
		Baphia nitida	1	6.5	0.559	Moraceae	Green
		Blighia sapida	4	18.1	0.762	Sapindaceae	Green
		Blighia unijugata	1	3.00	0.508	Sapindaceae	Green
		Bussea occidentalis	2	27.25	0.792	Caesalpiniaceae	Green
		Calycobolus africanus	3	2.53		Convolvulaceae	Green
		Ceiba pentandra	1	90.0	0.32	Bombacaceae	Green
		Celtis mildbraedii	9	45.37	0.59	Ulmaceae	Green
		Celtis zenkeri	4	15.6	0.61	Ulmaceae	Green
		Cleidion gabonicum	23	3.6	0.64	Euphorbiaceae	Green
		Cola gigantea	1	62.0	0.48	Sterculiaceae	Green
		Combretum smeathmannii	1	2.1		Combretaceae	Green
		Entandrophragma candollei	1	12.8	0.632	Meliaceae	Scarlet
		Funtumia elastica	4	24.75	0.51	Apocynaceae	Pink
		Griffonia simplicifolia	3	3.87		Caesalpiniaceae	Green
		Guarea cedrata	1	12.8	0.608	Meliaceae	Pink
		Hannoa klaineana	1	20.2	0.64	Simaroubaceae	Green
		Hymenostegia afzelii	1	1.00	0.824	Caesalpiniaceae	Green
		Lannea welwitschii	3	15.47	0.45	Anacardiaceae	Green
		Manniophyton fulvum	2	2.10		Euphorbiaceae	Green
		Microdesmis puberula	5	2.38	0.64	Pandaceae	Green
		Morus mesozygia	1	80.0	0.726	Moraceae	Green
		Myrianthus arboreus	1	16.6	0.43	Moraceae	Green
		Napoleonaea vogelii	3	2.33	0.69	Lecythidaceae	Green
		Nesogordonia papaverifera	3	19.3	0.74	Sterculiaceae	Pink
		Petersianthus macrocarpus	1	94.0	0.8	Lecythidaceae	Green
		Pouteria altissima	1	39.0	0.53	Sapotaceae	Red
		Pterygota macrocarpa	2	19.75	0.56	Sterculiaceae	Red
		Pycnanthus angolensis	1	110.0	0.652	Myristicaceae	Pink
		Rinorea oblongifolia	2	3.4	0.64	Violaceae	Green
		Sterculia oblonga	2	12.0	0.582	Sterculiaceae	Green
		Sterculia rhinopetala	6	25.62	0.768	Sterculiaceae	Pink

		Strombosia glaucescens	2	3.15	0.896	Olacaceae	Pink
		Trichilia prieuriana	2	14.6	0.63	Meliaceae	Green
		Triplochiton scleroxylon	5	77.6	0.384	Sterculiaceae	Scarlet
		Turraeanthus africanus	2	25.25	0.56	Meliaceae	Pink
		Vitex ferruginea	1	2.7	0.448	Verbenaceae	green
Fallow land	**1**	*Albizia adentifolia*	1	3.0	0.51	Mimosaceae	Scarlet
		Albizia zygia	3	36.6	0.49	Mimosaceae	Green
		Antiaris toxicaria	1	11.2	0.43	Moraceae	Pink
		Blighia sapida	3	20.28	0.762	Sapindaceae	Green
		Cola califolia	1	14.3		Sterculiaceae	
	2	*Albizia adentifolia*	1	7.0	0.51	Mimosaceae	Scarlet
		Albizia zygia	6	31.1	0.49	Mimosaceae	Green
		Blighia sapida	2	29.98	0.762	Sapindaceae	Green
		Cordia millenii	2	23.93		Boraginaceae	
		Funtumia elastica	2	17.13	0.51	Apocynaceae	Pink
		Albizia adentifolia	1	7.0	0.51	Mimosaceae	Scarlet
		Albizia zygia	1	27.05	0.49	Mimosaceae	Green
		Alstonia boonei	1	22.75	0.416	Apocynaceae	Green
		Blighia sapida	12	18.17	0.762	Sapindaceae	Green
		Cola califolia	2	7.3		Sterculiaceae	
		Funtumia elastica	4	16.13	0.51	Apocynaceae	Pink
		Lannea welwitschii	1	15.6	0.45	Anacardiaceae	Green
		Lecaniodiscus cupanioides	4	11.25		Sapindaceae	Green
		Milicia excelsa	1	8.6		Moracceae	Scarlet
		Sterculia tragacantha	1	7.05		Sterculiaceae	Green
Cropland	1	*Morinda lucida*	2	2.83		Rubiaceae	Green
	1	*Venonia spp.*		5.55		compositae	
	2	*Elaeis guineensis*	1			Palmaceae	
	2	*Spondias mombiri*	3	13.98		Anacardiaceae	
	3	*Blighia sapida*	1	57.85	0.762	Sapindaceae	Green
Teak plantation	**1**	*Astonia boonii*	6	5.13		Apocynaceae	Green
	1	*Tectona grandis*	44	17.64		Lamiaceae	

	2	*Astonia boonii*	3	21.74		Apocynaceae	Green
	2	*Terminalia superba*	1	19.25		Mimosaceae	Red
	2	*Tectona grandis*	43	19.32		Lamiaceae	
	3	*Tectona grandis*	131	9.39		Lamiaceae	

*** Star rating depicts the conservation priority of species. Black, Gold, Blue and Green stars decrease in order of conservation priority. Reddish (ie Scarlet, Red, Pink) star are green star species which are frequently exploited (Hawthorne, 1993)**

Appendix III

Shrubs and small plants

Land use	Species	Life form	Frequency		
			Plot 1	Plot 2	Plot 3
Cropland	*Acalyplis celiata*			5	
	Agerantum conysoides	Shrub		55	335
	Albizia adiantifolia	Tree			2
	Antiaris toxicaria	Tree			1
	Aspilia africana	Climber			3
	Baphia nitida	Tree			2
	Bidens pilosa		211		1
	Blighia unijugata	Tree	5		
	Cardiospormum grandifolorum		2		
	Centrocema pubescens	Climber	1	8	11
	Chromoleana odorata	Shrub	3	7	108
	Cleome rutidosperma	Herb	1		
	Clerodendron spledidum	Climber			14
	Cnestis ferruginea	Climber		2	
	Combretum smeathmannii	Liana			2
	Combretum zenkeri	Liana		11	
	Commellina banglansis				1
	Euphobia herterophylla	Shrub	1		
	Euphobia Lirta	Shrub	2		
	Ficus exasperata	Tree		1	
	Gongronema latifolium		3		
	Griffonia simplicifolia	Liana		1	1
	Ipomeo herterophytha	Climber			1
	Jastacia fiava	Shrub		6	
	Lecanoidiscus capanoides	Tree			1
	Malotus oppositifolius	Shrub		111	7
	Millettia thoningii	Tree	1		
	Millettia zechiana	Tree	1		24
	Mimosa pigra	Shrub		1	
	Mimosa pudica	Shrub	43		
	Morinda lucida	Tree		3	
	Motendra guineensis	Climber	1		
	Oplesmanus bermannii				3
	Panicum maximum	Grass		3	
	Phyllathus uninaris	Shrub	13	1	2
	Psiduuin guajava	Tree		1	
	Rourea coccine	Climber	1		
	Salacia spp	Creeper		13	5
	Sida acuta	Shrub	2		

	Solanum crienluum	Shrub			1
	Synedrlla nodifolia	Shrub		51	1
	Tridax procumbens	Shrub	82		
	Twanum triangulare		4		
	Vernonia cinerea	Shrub	90		11
Fallow land	*Antiaris toxicaria*	Tree	1		
	Baphia nitida	Tree	2		
	Cola califolia	Tree	1		
	Griffonia simplicifolia	Liana	25		
	Simila krosiana	Creeper			
	Sterculia tragacantha	Tree	2		
Teak plantation	*Blighia sapida*	Tree		2	
	Eleacis guineensis	Tree	1	1	
	Malotus oppositifolius	Shrub	1	2	
	Salacia spp	Creeper		3	
Natural forest	*Acacia pennata*	Tree	2	1	1
	Alafia baterii	Liana	4	15	3
	Albizia zygia	Tree		1	
	Antiaris toxicaria	Tree			2
	Bailsia bilonii			1	
	Baphia nitida	Tree	2	2	
	Blighia sapida	Tree	24	2	2
	Calycobolus africanus	Liana	13	25	10
	Celtis zenkeri	Tree	5		1
	Cissus araloides	Climber		2	
	Cissus producta	Climber		1	
	Cleidion gabonicum	Tree	6	2	11
	Cola gigantea	Tree			1
	Craterispermum caudatum	Tree		3	
	Culcasia striolata		4	38	90
	Dioscoreophyllum cumminsii		2	2	
	Funtumia elastica	Tree		1	1
	Gongronema latifolium			1	
	Gouania longipetala			1	1
	Griffonia simplicifolia	Shrub	28	13	18
	Guarea cedrata	Tree	1		1
	Hippocratea africana	Liana		1	
	Hymenostegia afzelii	Tree	1		
	Leptaspis cochleata		12		
	Microdesmis puberula	Tree		1	
	Millettia chrysophylla	Liana		2	
	Motandra guineensis	Climber		3	
	Nesogordonia papaverifera	Tree	10	7	4
	Olax genibecola	Shrub		1	
	Paullina pinnata	Shrub	4		

	Pouteria altissima	Tree	94		
	Rinorea oblongifolia	Tree	1	3	
	Smilax kraussiana	Creeper	1	4	
	Strombosia glaucescens	Tree	8	1	
	Tragia spanthulata	Creeper		1	
	Trichilia prieureana	Tree	1		
	Xylia evansii	Tree	2		

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

CARBON SEQUESTRATION IN FOUR LAND USE SYSTEMS IN A MOIST SEMI DECIDUOUS ECOLOGICAL ZONE OF GHANA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR AWARD OF MASTER OF SCIENCE DEGREE IN ENVIRONMENTAL SCIENCE

BY

Grace Gyabaah B.Sc (Hons.)

June, 2012

DECLARATION

I hearby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge it contains no material previously published by another person or material which has been accepted for the award of any other degree of the university, except where the acknowledgement has been made in the text.

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(Supervisor) Signature Date

REV.STEPHEN AKEAMPONG ……………………. …………………………..

(Head of Department) Signature Date

DEDICATION

This work is dedicated to my parents, Mr & Mrs Paul, Dora Gyabaah.

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ABSTRACT

Carbon sequestration potential of four land use systems, namely; Natural forest, Teak plantation, fallow land and cropland were assessed in a moist semi deciduous ecological zone of Ghana. Natural forest data were taken from Bobiri Forest Reserve while data on other land use systems were collected from compound of Forestry Research Institute of Ghana. The main aim of the study was to assess the contribution of four land use systems in ameliorating global warming through reduction of atmospheric carbon and also to assess the change in amount of carbon lost or gained when one land use is converted to another. Out of the six carbon pools of terrestrial ecosystem, carbon sequestration of four (aboveground, litter, herbs and soils) were experimentally assessed and one was extrapolated (belowground) from data of aboveground carbon. Total carbon was highest in natural forest, followed by teak plantation. Fallow land had a marginal increase in total carbon compared to cropland which had the least. Aboveground carbon was highest in natural forest and teak plantation. Fallow land and cropland however had their most carbon in soils. Litter carbon was more appreciable in teak plantation mainly because of broader and much lignified nature of Teak leaves that prevents it from decomposing easily. It was observed that converting natural forest to any of the land use types result in emission of CO_2 and reforesting Fallow and Crop lands to teak plantation results in removal of atmospheric carbon (Removal Factor) but conversion of natural forest to teak plantation results in CO_2 emissions (Emission Factor). It is concluded that enhancing natural forest to sequester carbon and also cultivation of teak plantation would be more appropriate among the four land use systems when carbon sequestration option is being considered. Fallow lands could be enhanced through improved fallowing rather than resulting to natural fallow. Agroforestry as opposed to slash and burn agriculture is recommended for improved CO_2 sequestration. These mitigation options would in the long run, seek to reduce the problem of climate change.

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LIST OF ABBREVIATIONS

CDM	Clean Development Mechanism
COP	Conference of Parties
CSIRO	Commonwealth Scientific and Industrial Research Organization
DBH	Diameter at Breast Height
DOC	Dissolved organic Carbon
FAO	Food and Agriculture Organization
GHG	Greenhouse Gas
HIPC	Highly Indebted Poor Countries
Max	Maximum
Min	Minimum
NASA	National Aeronautics and Space Administration
REDD	Reducing Emissions from Forest Deforestation and Degradation
REDD+	Reducing Emissions from Forest Deforestation and Degradation (Developing Countries; and the role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks)
SD	Standard Deviation
SOM	Soil Organic Matter
TSP	Temporary Sample Plot
UNDP	United Nations Development Programme
UNFCCC	United Nation Framework Convention on Climate Change